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UR-335

Health and Biology

THE UNIVERSITY OF ROCHESTER
Atomic Energy Project
P. O. Box 287, Station 3
Rochester 20, New York

44952

Contract W-7401-eng-49

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STUDY ON FLASH BURNS: THE INFLUENCE OF ULTRAVIOLET
RADIATION ON THE PRODUCTION OF CUTANEOUS BURNS

by:

Kelly M. Berkley

Division: Special Programs

Division Head: H. A. Blair

Section: Flash Burns

Section Head: H. D. Kingsley

Submitted by: Henry A. Blair,
Director

Date of Report: 7/1/54

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STUDY ON FLASH BURNS:
THE INFLUENCE OF ULTRAVIOLET RADIATION ON THE
PRODUCTION OF CUTANEOUS BURNS.

By

Kelly M. Berkley

ABSTRACT

Radiant energy of wavelengths shorter than 3200 Å was excluded by Pyrex glass in producing cutaneous burns in the pig with the carbon arc source. The 50% effective exposures for burns so produced were compared with those exposures required with the carbon arc source alone at 0.5 sec. exposure times.

It was found that exclusion of the shorter ultraviolet wavelengths increased the 50% effective exposure of radiation required to produce 1+, 2+, 3+ and 4+ burns. Ultraviolet radiation had a most marked effect in producing erythema (1+ burn); the 50% effective exposure was increased two-fold with its exclusion. No effect was observed in the 50% effective exposure for the threshold of complete transepidermal damage judged by depth of damage microscopically produced with or without the short wavelength radiation.

INTRODUCTION

The production of cutaneous burns by radiant energy from a modified carbon arc searchlight has facilitated the laboratory study of the effect of many physical factors. The burns from short exposures to high intensity radiant energy from this source are very similar to those produced by atomic weapons (7).

A monitoring apparatus was developed in this laboratory to record the intensity of radiation at the moment of exposure (3). A Pyrex glass plate in this monitoring apparatus altered the spectral characteristics of the radiation from the carbon arc source by eliminating much of the ultraviolet. It has been shown qualitatively (1) that such exclusion of ultraviolet energy caused an increase in the energy required to produce a given burn as judged by surface appearance but not when evaluated by depth of damage. Furthermore, the erythema produced by the unchanged carbon arc source was uniformly pink and blanched with pressure. That produced without ultraviolet radiation by using the Pyrex plate was spotty, dark red and did not blanch.

Our objective in this study was to quantitate the effect both by gross and microscopic examination of the exclusion of ultraviolet radiation on the production of burns.

METHODS

Equipment

A Corps of Engineers 24" carbon arc searchlight modified by an ellipsoidal mirror was used to produce the burns (3).

In the monitoring apparatus a sheet of clear polished Pyrex glass was mounted at an angle of about 57° to the optic axis and placed so that all the radiant energy in the beam must pass through it before striking the subject. The transmission of the glass at $3000 \text{ \AA}$ is only about 5%; therefore, it virtually eliminates the maximum erythema effective-ness band at $2980 \text{ \AA}$. Above $3600 \text{ \AA}$ the transmission is about 87% out to the long wavelength cut-off at approximately $25,000 \text{ \AA}$.

Design

Chester White pigs were used, weighing between 9.8 and 16.6 Kg. They were anesthetized by the intraperitoneal route with Dial in Urea-urethane (Ciba) (4), 70 mg/kg body weight. In preparation for burning, the skin was closely clipped and gently sponged with a damp cloth. The side of an animal was divided into three rows and seven columns to produce 21 subareas.

In the first group of eight animals (A), 24 replications at each of nine irradiances were made with radiation modified by the Pyrex glass. Twenty-four replications at each of five irradiances were also made with the unmodified carbon arc source. Exposures were systematically randomized so that each of the 14 combinations of irradiances with or without the Pyrex glass occurred three times on one animal and at least one time in each of the three rows on either side of the animal. In order to fill in the data of Group A, a second group of four animals was burned.

In this group (B), 24 replications were given at each of four diaphragm settings with the monitor and three diaphragm settings without the monitor. Exposures were systematically randomized so that each combination occurred once in each of three rows on each side of the animal.

With both groups the exposure time was 0.5 sec.

Evaluation

The lesions were evaluated 24 hours after burning and graded by the classification previously described (6, 8). A tabular summary of these criteria follows:

Laboratory Grade	Surface Appearance	Descriptive Term
1+	Erythema	Red Burn
2+	Patchy Coagulation	Spotted White Burn
3+	Uniform Coagulation	White Burn
4+	Steam Bleb	Blebbled White Burn

One hundred forty-eight of the burns were biopsied 24 hours after burning, fixed in Bouin's solution, and stained by hematoxylin and eosin. The evaluation of the injury follows the method previously described (8). The line of demarcation between damaged and undamaged collagen was measured with the aid of a micrometer scale in the ocular of the microscope. This disregards the depth of damage of the epithelial cells along the hair follicles.

The gradations of injury used are designated:

1. Epidermal: a portion or all of the cells of the epidermis are stained acidophilic, but there is no separation at the epidermal-dermal interface.

2. Transepidermal: with increasing injury, a separation of distorted cells occurs at the epidermal-dermal interface. This may be focal or complete separation, and this forms the basis for subdivision.

3. Dermal: the damaged collagen appears homogeneous and individual fibers become swollen. A line of horizontal demarcation delimits the depth of damage. To this line the depth is measured. The lesions are classed into groups which measure in depth from 0-0.5 mm, 0.5-1.0 mm and 1.0-1.6 mm, and termed superficial, mid and deep dermal damage. The average depth of the dermis is 1.6 mm.

RESULTS

A marked difference was noted in the appearance of 1+ burns produced by the carbon arc source alone and those modified by the Pyrex glass of the monitoring apparatus. The 1+ burns produced with the unmodified arc were uniformly pink with a six to eight hour latent period of appearance. The erythema blanched on pressure. Damage as observed microscopically was confined to the epidermis. On the other hand, the 1+ burns produced by radiation modified by the Pyrex glass were quite different. The burns were spotty and dark red. The color appeared immediately, and became intensified with elapsed time, but did not blanch on pressure. On microscopic examination there were focal areas of epidermal-dermal separation. Thus, the redness would appear to be produced by a direct fixation of the capillaries in the subpapillary plexus, the spots occurring where the rete pegs project and the epidermis was thinnest.

The estimation of the 50% effective exposure by the Litchfield and Wilcoxon method (5) was done for burns produced both by the carbon arc source alone and those modified by the Pyrex glass plate of the monitoring apparatus.

Table 1 is a summary of the results produced by unmodified radiation of the carbon arc source. The first column lists the group of animals for which the corresponding irradiance and radiant exposure was used. The number and percentage of lesions as evaluated by surface appearance are listed for each radiant exposure. Table 1a lists the 50% effective exposure and 0.95 confidence intervals for 1+, 2+, 3+ and 4+ burns.

Table 2 and 2a is a similarly constructed table for lesions produced by radiation modified by the Pyrex plate of the monitoring apparatus.

A comparison of the 50% effective exposure and 0.95 confidence interval is depicted in figure 1. It can be seen that for 1+, 2+, 3+ and 4+ burns the 50% effective exposure of modified radiation is higher than that of unmodified radiation. This increase is significant at the 0.95 level of confidence for 1+ and 2+ burns, but not for 3+ and 4+ burns. At the erythema level (1+) there is a two-fold increase from 1.4 cal/cm² to 2.9 cal/cm². At this grade the increase is maximal.

Tables 3 and 4 list the response, as evaluated microscopically, produced by unmodified and modified radiation respectively. The 50% effective exposure for the grade of complete transepidermal damage is approximately 4.6 cal/cm² for both modified and unmodified radiation, as determined by linear interpolation of the data.

DISCUSSION

As shown, the elimination of incident energy of wavelengths below 3200 Å from the carbon arc source raised the 50% effective exposure required to produce 1+, 2+, 3+ and 4+ burns at 0.5 sec. exposures. The 50% effective exposure for 1+ burns was raised two-fold, that for 2+ burns to a lesser but significant extent. For 3+ and 4+ burns although

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Table 1

RESULTS OF EVALUATION OF SURFACE APPEARANCE

Group	Irradiance (cal/cm ² /sec)	Total No. of Exposures	Radiant Exposure (cal/cm ²)	No Burn 0	Erythema 1+	Patchy Coagula- tion 2+	Total Coagula- tion 3+	Steam Bleb 4+	Carbon- ization 5+
B	2.0	24	1.0	23 (96%)	1 (4%)				
A	3.4	18	1.7	4 (22%)	14 (78%)				
B	7.4	24	3.7		4 (18%)	19 (78%)	1 (4%)		
A	9.4	19	4.7			13 (68%)	4 (21%)	2 (11%)	
B	14.0	24	7.0				24 (100%)		
A	18.4	24	9.2				17 (74%)	6 (26%)	
A	22.4	23	11.2				3 (14%)	19 (86%)	
A	34.4	22	17.2					17 (77%)	5 (23%)

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Table 1a

Laboratory Grade	50% Effective Exposure (cal/cm ²)	0.95 Confidence Interval (cal/cm ²)
1+	1.4	1.3 - 1.7
2+	3.2	2.9 - 3.5
3+	5.1	4.5 - 5.7
4+	8.7	5.6 -13.8

Table 1 shows for the stated irradiance and radiant exposure the number and percentage of lesions of each grade of severity, produced by the unmodified carbon arc source.

Table 1a shows the 50% effective exposures and 0.95 confidence intervals for 1+, 2+, 3+ and 4+ burns.

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RESULTS OF EVALUATION OF SURFACE APPEARANCE

Group	Average Irradiance (cal/cm ² /sec)	Total No. of Exposures	Average Radiant Exposure (cal/cm ²)	No Burn 0	Erythema 1+	Patchy Coagulation 2+	Total Coagulation 3+	Steam Bleb 4+	Carboni- zation 5+
B	4.5	24	2.3	23 (96%)	1 (4%)				
B	6.5	24	3.3	2 (8%)	22 (92%)				
A	7.6	24	3.8	2 (8%)	14 (58%)	8 (33%)			
A	8.1	23	4.1		9 (39%)	13 (56%)	1 (4.5%)		
A	8.9	24	4.5		4 (17%)	19 (79%)	1 (4%)		
A	10.1	23	5.1		2 (9%)	19 (83%)	2 (9%)		
B	11.0	24	5.5			9 (37%)	15 (63%)		
B	12.8	24	6.4			1 (4%)	23 (92%)		
A	15.2	25	7.6			1 (4%)	24 (96%)		
A	16.5	24	8.3			1 (4%)	21 (87%)	2 (8%)	
A	18.4	25	9.2				21 (84%)	4 (16%)	
A	21.6	24	10.8				10 (43%)	13 (52%)	1 (4%)
A	28.3	22	14.2				2 (9%)	16 (73%)	4 (18%)

Table 2a

Laboratory Grade	50% Effective Exposure (cal/cm ²)	0.95 Confidence Interval (cal/cm ²)
1+	2.9	2.7 - 3.2
2+	4.0	3.8 - 4.2
3+	5.5	4.6 - 6.6
4+	10.6	9.8 - 11.5

Table 2 shows for the stated irradiance and radiant exposure the number and percentage of lesions of each grade of severity, produced by the carbon arc source modified by the Pyrex glass plate.

Table 2a shows the 50% effective exposures and 0.95 confidence intervals for 1+, 2+, 3+ and 4+ burns.

FIGURE 1

THIS FIGURE SHOWS THE EFFECT OF THE EXCLUSION OF ULTRAVIOLET RADIATION BELOW 3200 A° FROM THE CARBON ARC SOURCE BY PYREX GLASS ON THE 50% EFFECTIVE EXPOSURE OF ENERGY REQUIRED TO PRODUCE 1+, 2+, 3+ AND 4+ BURNS.

Table 3

RESULTS OF EVALUATION OF DEPTH OF DAMAGE

Group	Radiant Exposure (cal/cm ²)	Epidermal Acidophilism	Transepidermal		Dermal Damage			No. of Burns Examined
			Focal	Complete	Super- ficial	Mid	Deep	
A	1.7	1						1
B	3.7	6						6
A	4.7		3	3	1			7
B	7.0			1	7			8
A	9.2				6	4	1	11
A	11.2				3	4	2	9
A	17.2				1	3	5	9

This table shows the number of burns examined showing the indicated degree of severity as judged by depth of damage at the stated radiant exposure of unmodified energy from the carbon arc source.

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Table 4

RESULTS OF EVALUATION OF DEPTH OF DAMAGE

Group	Radiant Exposure (cal/cm ²)	Epidermal Acidophilism	Transepidermal		Dermal Damage			No. of Burns Examined
			Focal	Complete	Super- ficial	Mid	Deep	
A	3.8	1	1		1			3
A	4.1	1	3	1	1			6
A	4.5		6	1				7
A	5.1		3	3	1			7
B	5.5		2	6				8
B	6.4		1	2	5			8
A	7.6			2	6	4		12
A	8.3		1	1	10	2		12
A	9.2				7	6		13
A	10.8				3	6	5	14
A	14.2				3	7	3	13

This table shows the number of burns examined showing the indicated degree of severity as judged by depth of damage at the stated radiant exposure of energy from the carbon arc source modified by Pyrex glass.

there was an increase, it was not significant at the 0.95 level of confidence. There was no change in the estimate made by linear interpolation of the 50% effective exposure for complete transepidermal burns.

The marked difference in the surface appearance and the energy requirements of 1+ burns produced by the carbon arc source alone and from those produced by radiation modified by the Pyrex plate is best explained by the known specific effect of short wavelength radiation.* Ultraviolet radiation, which is largely absorbed in the epidermis, is known to have a specific action spectra for erythema production with maximum effectiveness at 2980 Å (2). Thus it is quite understandable that more energy is required to produce 1+ burns when the maximum erythema band is excluded by the Pyrex plate.

The erythema produced by ultraviolet radiation is probably the result of the elaboration of a vasodilator substance which diffuses to the subpapillary capillary plexus. The uniformity, latent period and blanching with pressure is consistent with characteristics which have been described for the photochemical effect of ultraviolet radiation. On the other hand the spotty, fixed and instantaneous erythema produced by radiation without short wavelengths could be explained by a direct fixation of the capillaries in the subpapillary capillary plexus by a non-specific radiant energy stimulus.

The small increase in the energy requirements for 2+, 3+ and 4+ burns although only significant at the 0.95 level of confidence for 2+ burns can probably be explained by the dependence upon wavelength of the

*Widmark in 1889 showed that rays of the carbon arc passing through quartz produced sunburn, whereas those rays passing through glass did not. (Quoted by Blum (2)). This set the long wavelength limit for sunburn somewhere in the ultraviolet, as glass cuts out much of the ultraviolet radiation which is passed by quartz.

reflectance of skin. If reflectance increases with increasing wavelength and less of the incident energy is absorbed by the skin, more energy will be required to produce a burn of given severity with long than with short wavelength radiation. The surface appearance of 2+ and 3+ burns reflect damage through the epidermis.

It is to be noted that there was no difference in energy requirements for complete transepidermal burns as judged by depth of damage microscopically, but the data is limited.

CONCLUSIONS

1. The exclusion of ultraviolet radiation to 3200 Å increased the 50% effective exposure of radiation required to produce 1+, 2+, 3+ and 4+ burns at 0.5 sec. exposures.

2. The presence or absence of wavelengths below 3200 Å from the carbon arc source caused no difference in the 50% effective exposure of energy required to produce burns which were evaluated microscopically by depth of damage. The 50% effective exposure for the threshold of complete transepidermal damage is 4.6 cal/cm² for radiation with and without ultraviolet radiation.

3. Ultraviolet radiation has a marked effect in producing erythema but little effect in producing burns below the epidermis.

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